Fermi National Accelerator Laboratory

FERMILAB-Pub-76/31-EXP
2250.000

(Submitted to Nucl. Instr. and Methods)

THE DESIGN AND PERFORMANCE OF A HALO-FREE INTENSE EXTRACTED PROTON BEAM AT FERMILAB

B. Cox and C. T. Murphy

March 1976

Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration

THE DESIGN AND PERFORMANCE OF A HALO-FREE INTENSE EXTRACTED PROTON BEAM AT FERMILAB

B. COX and C. T. MURPHY

Fermi National Accelerator Laboratory, Batavia, Illinois 60510, U. S. A.

March 1976

A set of refocussing and collimation stages has been constructed in the Proton West beam line of the Proton Area at Fermi National Accelerator Laboratory which allows the operation of a halo-free intense proton beam. Measurements made at the first target point in the Proton West experimental hall demonstrate that this system is capable of targeting 10^{12} protons in a 4 mm diameter spot with a halo density of about 150 particles/mm^2 at a distance of 5.6 cm from the focus. This system has been operated at 200, 300, and 400 GeV.

1. Introduction

In order to operate the Proton West Experimental Area at Fermilab with intense proton beams at the transmission targets, a system of three beam-manipulation enclosures has been added to the Proton West beam line in order to reduce to a very low level the halo which accompanies the primary extracted proton beam. This halo results partly from various necessary materials in the beam, such as electrostatic septa in the three-way splitting station[1]), thin windows, and secondary emission monitors, and partly from the nonadiabatic process of extraction itself. This halo, which contains as much as 10% of the primary beam, intercepted the steel and coils of the pretarget quadrupoles 40 m upstream from the experimental apparatus, creating large backgrounds for the experiments. The system described here removes this halo about 300 m upstream of the experimental area with two sets of collimators which are orthogonal in phase space and sweeps off-momentum secondaries from the collimators out of the beam with bending magnets. The resulting backgrounds in the experimental hall have been reduced four orders of magnitude.

2. Design

The system of enclosures is shown in fig. 1, along with the optics of the refocussing system. The design of this system[2]) incorporates four stages:

1) Variable-aperture steel collimators, 1.5 m in length, remove angular tails which are already at large displacement in the first enclosure (PW-A). At this point, the beam is approximately parallel and the resulting strong displacement-angle correlation causes the halo of the incident proton beam to be far off the optical axis.

2) A quadrupole doublet in PW-A focusses the beam (parallel-to-point focus) in the second enclosure (PW-B) in order that a second pair of variable-aperture collimators in PW-B can absorb the remaining portion of the proton beam which had small displacement but large angle in PW-A. In a different language, the collimators in PW-B make a cut in phase space orthogonal to the collimators in PW-A (see fig. 2).

3) Magnetic bends of 2 and 4 mrad following the PW-A and PW-B collimators, respectively, sweep off-momentum secondaries from the collimator surfaces out of the beam. The collimators in the third enclosure (PW-C) are specifically intended to intercept such particles.

4) The quadrupole doublet in PW-C images the collimators in PW-B onto the entrance (point-to-point focus) of the pretarget quadrupoles in the experimental area. This condition insures that all on-momentum and off-momentum particles scattered from the jaws of the primary collimators and surviving the slit system fit within the 10 cm aperture of the pretarget quadrupoles.

The total effect of the system is more evident if the restricting apertures of the system are transformed to the entrance of the experimental area in a phase space plot, as shown in fig. 2. For the combination of quadrupole settings described, this superposition of apertures makes it necessary for a particle appearing outside of the bounded area to have passed through a considerable amount of steel. The complete bounding of the phase space plot by the collimator system makes it possible to produce a clean beam not only at the pretarget quadrupoles but also at all further focuses of the beam.

3. Performance

Since July of 1975 this system has operated at 200, 300, and 400 GeV and is capable of operation at 500 GeV. The proton beam halo was measured by a variety of monitors. The first monitor consisted of a three-element scintillation counter telescope oriented perpendicular to the beam at a distance of 1 m from the first pretarget quadrupole and measured the beam scattered from that quadrupole. This counter telescope registered 500 counts/10^{12} protons passing through the quadrupole. In comparison with a similar system that is operating in the Proton Center pretarget area (where there are no quadrupole enclosures) which registers 5×10^{6} counts/10^{12} protons, there is a factor of 10^{4} halo reduction.

A second monitor consisted of another three-element scintillation telescope oriented parallel to the beam line 30 cm upstream from the first target position in the experimental area (Experiment 95). This telescope measures the amount of halo which can actually strike flanges and other material near the target and is quite sensitive to the tune of the pretarget quadrupole doublet, which produces a sharp focus of the beam at this point (spot size 4.5 mm horizontally by 0.5 mm vertically). This telescope could be moved remotely transverse to the beam in order to produce a profile of the halo from 5.6 cm to 40 cm from the centerline. The results of this scan are shown in fig. 3. As indicated, the shape of the distribution is exponential out to 18 cm. The smallest counting rate at 5.6 cm from the beam centerline observed in this telescope was 150 counts/mm^2 per 10^{12} incident particles. This small halo allows placement of steel collimators in the spectrometer arms of Experiment 95 as close as 3 cm from the beam without generating an intolerable target-out counting rate at the end of the arms. The target-out counting rate in counters in the spectrometer arms 75 cm from the beam line is 4 counts/mm^2 per 10^{12} primary protons. This rate is also four orders of magnitude lower than the rate before the collimation system was installed.

We have measured the effect of the various collimators on the halo at the first target position. Each collimator was successively moved in and out of the beam and the halo was recorded as a function of collimator aperture. Fig. 4 shows a particular curve taken at 300 GeV for the first vertical collimator in the PW-B enclosure. A definite minimum is reached in the halo when the opening of the collimator is such that it is still hardly intruding into the primary beam but is tight enough to intercept the secondaries generated by the collimators in the PW-A enclosure.*

The halo rate with all collimators open (leaving 4 cm magnet apertures in each enclosure) is 15 times the rate with the collimator apertures optimized. Closing only the collimators in PW-A to their optimized apertures usually makes the halo larger than with all collimators open, showing that the second set of collimators in PW-B do serve the double function of intercepting primary halo and secondaries

* As an experiment, the collimator system has also been used to reduce the horizontal emittance of the beam by a factor of two, at the cost of increasing the halo by a factor of 5 and dumping 40% of the incident beam on the FW-A collimators. Because of radiation problems, this feature can be used only at intensities of around 10^{10} protons per pulse.

scattered from the collimators in PW-A. All of the above halo rates are subject to an uncontrollable variation of about a factor two, depending upon the exact nature of the incident beam. The collimator system does not entirely isolate the Proton West Area from variations in the Switchyard beam tuning.

The resulting beam is extremely sensitive to material in the beam. For instance, the halo is increased by a factor of five by the insertion of a titanium window of thickness 0.1 mm, 260 m upstream of the target point. The residual gas in the vacuum pipe between PW-B and the target point, at a pressure of 50μ, has been calculated to account for about half of the remaining halo.

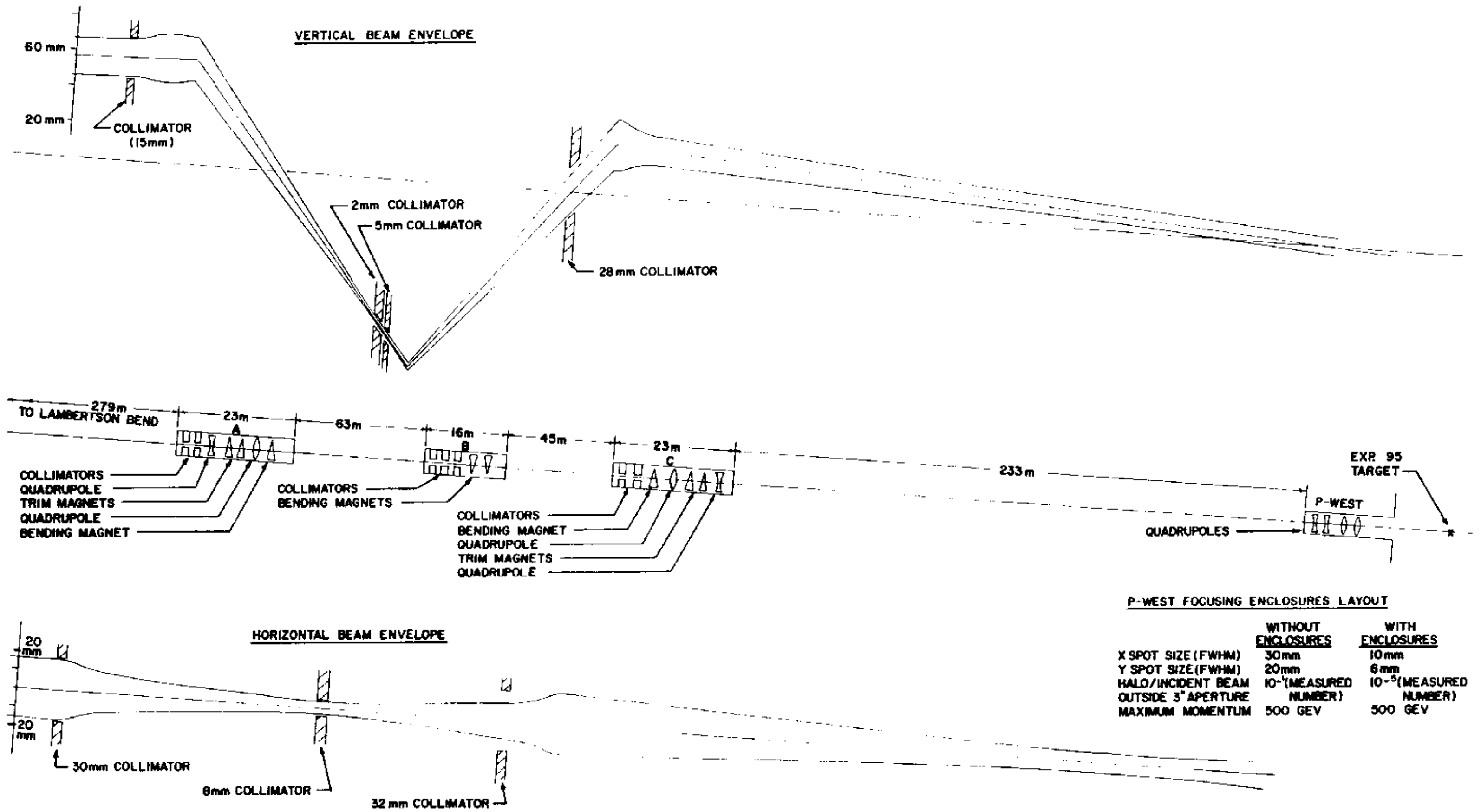
In conclusion, the existing system has produced an extremely clean beam with halo densities 10 orders of magnitude down from the proton beam intensity. In addition, the flexibility of the system is such that the experimenter can respond both to different conditions arising from main ring extraction differences on an hour-to-hour basis and to his differing experimental requirements by simple adjustments in order to maintain the quality of the beam.

We gratefully acknowledge the hard work of the entire staff of the Proton Department in the execution of this project. We also thank John Peoples for important contributions, the early experimenters from Experiments 95 and 177 for their assistance, and Robert Wilson for his support of the project.

References

[1]) B. Cox, C. T. Murphy and J. Peoples, Fermi National Accelerator Laboratory Internal Report TM-491, 1974.

[2]) B. Cox and C. T. Murphy, Fermi National Accelerator Laboratory Internal Report TM-492, 1974.



P-WEST FOCUSING ENCLOSURES LAYOUT

	WITHOUT ENCLOSURES	WITH ENCLOSURES
X SPOT SIZE (FWHM)	30mm	10mm
Y SPOT SIZE (FWHM)	20mm	6mm
HALO/INCIDENT BEAM OUTSIDE 3" APERTURE	10^{-4} (MEASURED NUMBER)	10^{-5} (MEASURED NUMBER)
MAXIMUM MOMENTUM	500 GEV	500 GEV

Fig. 1. Schematic layout and optics of the halo-removal system. The quoted spot sizes are at the entrance to the Proton West pretarget tunnel.

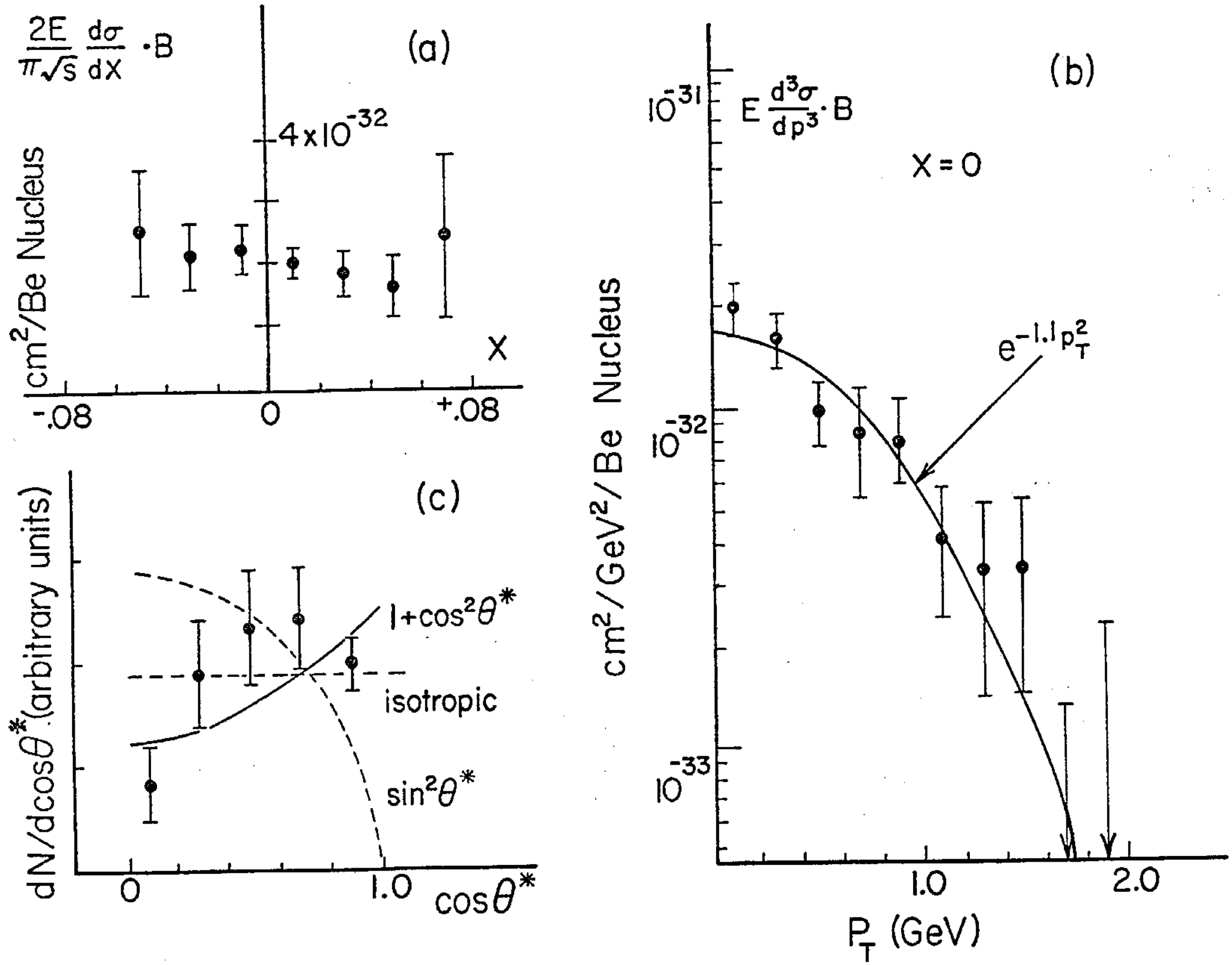


Fig. 2. ψ(3100) Cross Sections: (a) Invariant cross section versus $x \equiv P_{\parallel}^{cm}/P_{max}^{cm}$ (integrated over over p_t^2). (b) Invariant cross section versus p_t near $x = 0$. (c) Decay angle distribution in the helicity frame of the ψ. (Plotted errors are statistical only.)

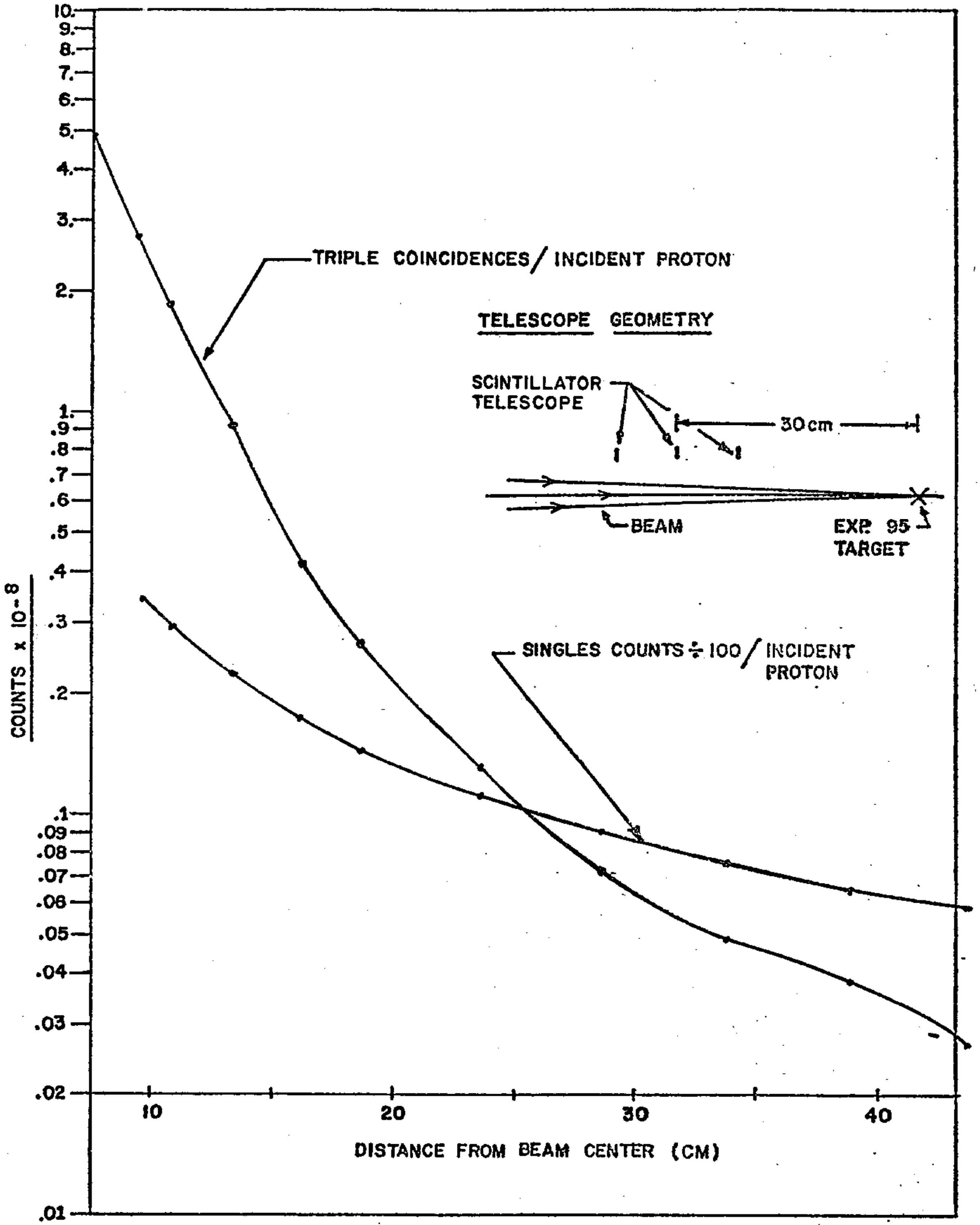


Fig. 3. Beam halo as a function of transverse distance from the beam centerline as measured by a scintillator telescope near the first target position.

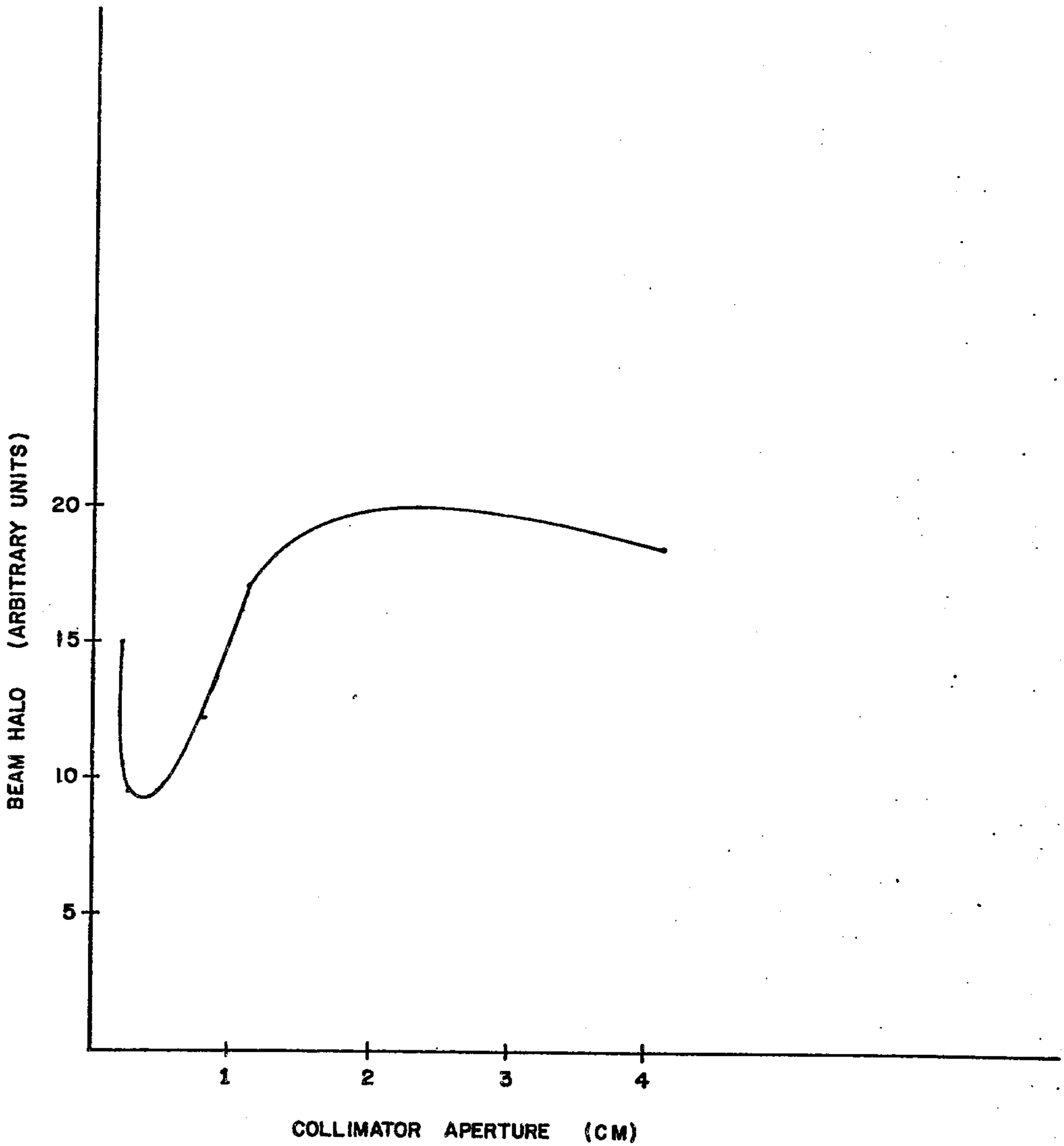


Fig. 4. Beam halo as a function of the aperture of the first vertical collimator in Enclosure PW-B as measured by the same scintillator telescope shown in Fig. 3. Other collimators in the system were at their optimum settings (minimum halo).